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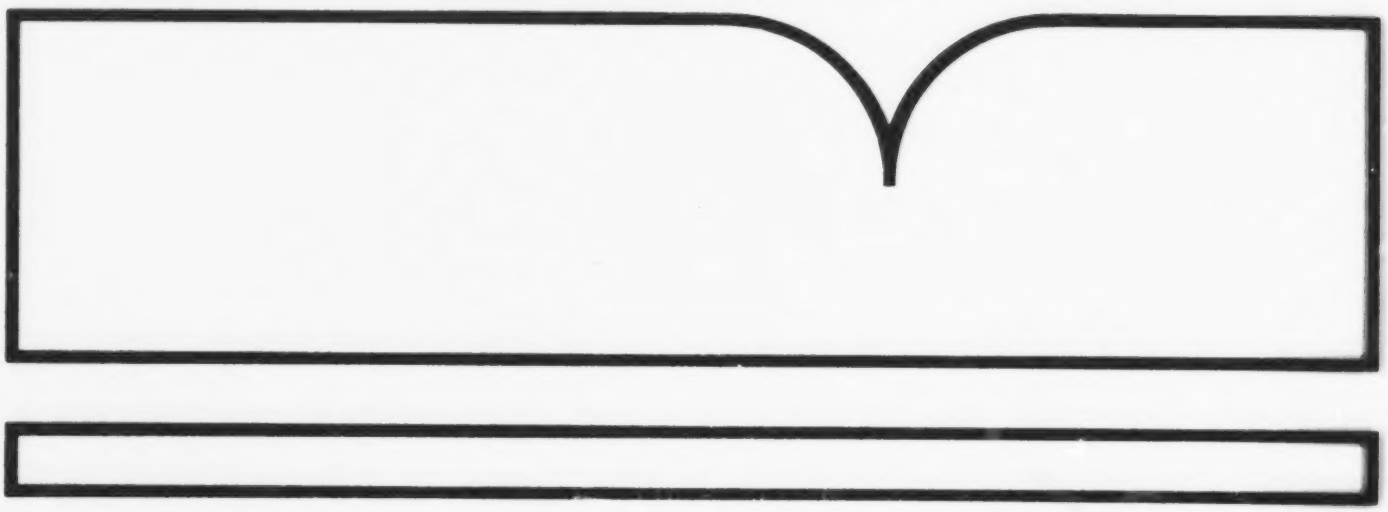

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SOURCE CONTROL TECHNIQUES FOR ACID MINE DRAINAGE

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16. ABSTRACT

The potential for production of acidic discharges from mining activities is related to the pyritic concentration in the overburden and to the available alkalinity. Exposure of the pyritic material to weathering causes oxidation and the release of sulfuric acid. Source control techniques include pyrite segregation and selective burial, use of bacteriacides to retard bacterial catalysis, use of alkaline reagents to provide in-situ treatment, and the use of treatment systems to neutralize acidic drainages.

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ACID MINE DRAINAGE

Acid drainages are, geologically speaking, old news. What is commonly referred to as Acid Mine Drainage (AMD), which is now universally associated with mining, existed eons before any mining began. The formation of acid discharges can be a natural process. The acidity is formed when pyrite, which is iron disulfide - a naturally-occurring mineral, is typically exposed to water and oxygen and oxidizes, forming a weak solution of sulfuric acid. The low pH solution then dissolves the acid-soluble metals in the surrounding strata, yielding a discharge containing such common metals as iron, manganese, magnesium, calcium, and sodium, plus trace levels of toxics like arsenic, selenium, beryllium, uranium, cadmium, copper, etc. The pH of the solution may be as low as pH 2.

Although the phenomena of pyritic oxidation and acid drainage formation is "old as the hills," it is unfortunately true that mining activities grossly accelerate this process by exposing pyrite. Pyrite is a very common mineral and occurs naturally both within the ore bodies and within the strata surrounding those ore bodies. The mining and milling processes expose huge surface areas for potential weathering and subsequent acid production. It is not uncommon for a system that was alkaline prior to mining to turn strongly acid after mining.

Four factors control acid production:

- Type, abundance, and exposure of pyritic materials
- Oxygen
- Water
- Pyrite-oxidizing bacteria

Control of formation of acid mine drainage must address one or more of those factors. For example:

Type, abundance, and exposure of pyritic materials--Little can be done about the type of pyrite (some morphological forms produce more acid than others). The abundance is also tough to control except by pre-mining planning to selectively handle pyrite-containing materials, which really relates to controlling exposure, and involves attempting to minimize the availability of oxygen or water to the pyritic material.

Oxygen--Oxygen is the common element needed for pyrite oxidation, which leads to acid formation. Burial of acid-producing materials in backfills and mine sealing are common attempts to minimize the availability of oxygen to the pyritic materials. While reducing the oxygen levels does diminish acid production, there can be other oxidants (such as ferric hydroxide) that can oxidize pyrite. The rates are lower, however, for naturally occurring alternative oxidants than for oxygen.

Water--Water not only enters into the reaction, but primarily serves as the transport vehicle for the reaction products from pyrite oxidation. Reducing the water availability reduces the ability of the geosystem to "flush out" the products of oxidation, even though oxidation may have already taken place. Methods of infiltration control and selective burial are common techniques for controlling water inflow into pyritic materials during backfilling operations.

Pyrite-oxidizing bacteria--Pyrite-oxidizing bacteria exist in virtually all mine sites and grossly accelerate pyrite oxidation. These bacteria flourish under acidic environments but are not viable under neutral or basic pH conditions. Bacteria are very hard to control. Some attempts have been made with slow-release bacteriacides and these are now under study.

APPROACH TO CONTROL

Traditionally, the approach to at-source control has focused on isolating the pyritic material from oxygen and/or water. The process begins with identification of the pyritic material and segregation of that material. Exposure to weathering is minimized as much as possible by pre-mining planning to provide for selective handling and rapid burial of the potential acid-producing material. The choice of where to bury the material within the backfill is governed by the hydrology of the fill and whether or not the sources of recharge to the backfill are from the highwall or from infiltration or both. Keep it away from water. Again, traditionally, the slope of the fill and drainage system are designed to encourage rapid runoff and minimum infiltration. Cover soils and amendments are encouraged to support vegetation and prevent wind and water erosion. Repetitive applications of bacteriacides may significantly retard acid production. Use of synthetic liners will virtually eliminate infiltration and will reduce oxygen transport. Although the initial cost of these liners appears high, over the long term they might provide the most cost-effective alternative.

Don't overlook the possibility of failure. Some provision for water treatment should be formulated should acid discharges develop.

A promising remedial approach appears to be alkaline trenching, which is the purposeful enhancement of infiltration into the backfill through an alkaline medium such as sodium carbonate.

COVER SYSTEMS

Cover systems can serve several functions in controlling acid mine drainage: (1) reduce the spread of acid-producing materials by air and water erosion; (2) control surface flushing of acid materials to surface waters; (3) reduce or eliminate infiltration into and leaching of acid-producing materials; and (4) decrease the available oxygen that supports pyrite oxidation and microbial catalytic action.

Pyritic materials left on the ground surface are subject to oxidation and the formation of acidity. Precipitation and the resulting runoff then flush the acidic by-products into adjacent surface waters. In addition, pyritic material is moved by air and water to adjacent areas, thus spreading the source of AMD. A cover over the exposed pyritic material would eliminate this source of contaminants.

Water serves as the transport media flushing the acid products from the waste material into groundwater and ultimately to surface water systems. The reduction and/or elimination of infiltrating water can significantly reduce the release of acid products. Cover systems facilitate runoff and reduce infiltration, thus reducing AMD release.

Since oxygen is necessary for AMD production, the reduction and/or elimination of oxygen from the pyritic material can reduce the rate of AMD production. Cover systems can reduce oxygen transport.

Soil Covers

The early cover systems were made of a thin layer of soil and overburden. The thickness used was dictated by the depth needed to establish and maintain a vegetative cover.

If installed properly, i.e., proper depth, grading, and surface water control, these systems did significantly reduce erosion and flushing of acid products, but significant amounts of water and air still made their way to the pyritic material. In order to enhance soil covers, additives were applied to them including limestone, fly ash, and sewage sludge. The limestone was either mixed with the soil, with the upper layer of pyritic waste, or as a layer between the soil and waste. The purpose of the limestone was to provide alkalinity to neutralize the AMD, promote vegetative growth, and prevent upward movement of acid into the soil layer. Fly ash served a similar function, except that more material was required because of its lower alkalinity (but it was cheaper) and because its pozzolanic properties might reduce the permeability of the soil or waste and thus reduce the leaching rate. Sewage sludge was applied primarily to promote vegetation establishment and growth, but also added some alkalinity, organic matter, and fertility to the system.

The vegetation grown on soil cover systems not only helped in protecting the cover soil from air and water erosion, but utilized water, thus reducing the amount of water available for leaching. The decaying vegetation also acted as an oxygen sink, thus reducing the oxygen available for pyrite oxidation. On the other hand, a vegetative cover root system made the soil more permeable and more water infiltrated into the waste.

There is extensive literature[1,2] on soil covers; however, the effectiveness of most were based on vegetative establishment and growth, not on the reduction of AMD. There are two major reasons for this: (1) monitoring systems to evaluate the effectiveness of cover systems in the reduction of AMD are complex and costly; and (2) because of the large volumes of acid production in the waste systems, years of monitoring would be required to measure changes. In addition, normal variations in the hydrologic cycle made data interpretation very difficult. A commmon technique was to measure water quality in adjacent streams. This technique rarely proved successful for the above reasons.[3,4] In general, many people had a "gut" feeling that soil covers were reducing acid releases, but very little hard data was available to support the contention. A column study by Apel[5] provided some basis to support the contention that soil covers reduce acid production. In Apel's study, paired sets of 12-inch diameter columns were filled with 4 feet of pyritic mining waste from a sulfide ore mine. Two sets (pairs) served as controls and no amendments or surface treatments were used. Three surface treatments were examined: (1) the incorporation of sewage sludge, agricultural limestone, and fertilizer into the upper 6-inch layer of mine waste; (2) the layering of sewage sludge and fertilizer over the lime-treated waste (limestone was incorporated into the top 6 inches of wastes, and a mixture of fertilizer and sewage sludge was placed on top of the limestone-treated waste); and (3) the placement of 1.5, 2, and 4 feet of cover soil over the untreated waste. Grasses were planted on all columns and each column received identical irrigation in a greenhouse. The results of the study were dramatic, as shown in Table 1, where the data are expressed as percent reductions in total load as compared to the untreated control columns. Increasing the depth of cover soil was shown to increase its effectiveness in reducing load. A 4-foot cover soil reduced acid load 81 percent and decreased metals loads from 64 to 75 percent. This was as effective as incorporating limestone, sludge, and

fertilizer into the top 6 inches of waste. Thick soil covers were also advocated in the surface mining regulations promulgated by various states in the late 1970's. Up to 6 feet of cover were recommended. The major disadvantages to such thick covers were the high cost and sometimes the shortage of cover material.

Table 1: Experimental Column Percent Load DECREASES as Compared to the Untreated Mine Waste Control Columns.

	Acidity Load	Copper Load	Iron Load	Lead Load	Zinc Load
Incorporated mining waste/lime/sludge/ fertilizer	77	57	70	53	67
Fertilizer/sludge layered over lime-treated waste	65	43	60	58	51
1.5-ft Coversoil	58	55	55	75	57
2-ft Coversoil	71	54	66	79	54
4-ft Coversoil	81	64	74	75	66

Source: Apel[5]

The U.S. Environmental Protection Agency, as part of its Hazardous Waste Management Program, has prepared two Technical Resource Documents (TRD's) and a handbook as guidance in the design and installation of soil cover systems. The first TRD describes methods for "Evaluating Cover Systems for Solid and Hazardous Waste"[6], and the second describes a "Hydrologic Simulator Model"[7] for cover systems. The model takes engineering, hydrologic, and climatologic input data in the form of rainfall, average temperature, solar radiation, leaf area indices, and characteristics of cover material, and performs a sequential analysis to derive a water budget including the runoff, percolation, and evapotranspiration. The handbook on "Covers for Uncontrolled Hazardous Waste Sites"[8] provides guidance on the selection and design of cover systems.

Synthetic Covers

The use of synthetic covers is becoming more common in the control of leachates from hazardous waste facilities and, in fact, is required for hazardous waste landfills now in operation. Synthetic covers have the property that they are essentially impermeable. Impermeable materials restrict the movement of water and/or gas. The most common types of nonsoil, impermeable materials are bituminous materials such as asphalts and tars, polymeric membranes, concrete, and cement. Each of these are discussed in detail in reference 8. Synthetic membranes or geomembranes fall within three categories: elastomers (rubbers), thermoplastics, and combination of elastomers and thermoplastics, and would appear to have the greatest potential as covers for mining situations. If properly selected and installed, the synthetic membrane should result in essentially no water or oxygen entering the acid-producing mine waste from the atmosphere. However, they might enter from the groundwater system. When the water and air are eliminated, significant reduction in acid formation and leaching should result. Until just recently, however, synthetic membranes have not been applied to mining situations because of the high cost.

At two sites in West Virginia, PVC covers have been placed over acid mine waste and acid-producing mine spoil. At one site 160 acres of acid-producing sandstone were covered with 30-mil PVC. The other site (DLM Coal Company) was covered with 30-mil PVC, and 35 to 101 cm (14 to 40 inches) of native soil in some areas, or overburden material in other areas.[9] The site was a ridge top and the 45-acre top was PVC-covered and the 9-acre steep slopes along the edge were not. Two studies have been conducted at this site. Thurman and Sencindiver[10] studied the soil and water properties of the material on top of the PVC cover, and Caruccio and Geidel[11] studied the changes in acid seep volumes and loads, groundwater levels, reversals in hydraulic gradients, and possible changes in geochemistries of seep and acid regimes as a result of the PVC cover.

Thurman reported that ground cover was significantly greater, root growth was deeper, and distribution of roots was greater where native soil had been used as the cover material. Root growth where the overburden material was used was confined to the upper 12 cm, i.e., the depth that lime had been incorporated. Observation wells above the PVC cover showed that water reached the liner and saturated the overlying soil. Moreover, the water moved across the liner to the drainage system and did not build up above the cover with time. The cover soil did not slip off the PVC cover, and the stability of the soil cover appeared to be enhanced by a favorable texture and rock fragment content, and by compaction during construction. The vegetative cover on the surface aided in decreasing surface runoff and erosion, and thus held the soil on the site. On the other hand, it increased the amount of water infiltrating into the cover soil.

Caruccio and Geidel[12] monitored the seeps from below the cover and the groundwater level. Their data showed a 75 percent decrease in acid load from the two seeps below the PVC cover. In addition, they found that the well located below the PVC cover had a constant water level and was not influenced by precipitation events, indicating the cover was an effective barrier to water infiltration. On the other hand, the wells located in the uncovered area responded to precipitation events. Caruccio recommended that the entire area should be covered with the membrane for maximum control of AMD.

Although membrane installation costs may be high, savings in the cost of long-term treatment of the AMD may offset the cost of the liner.

pH Adjustment

Fortunately, not all pyritic-containing materials produce an acidic discharge. This is largely due to kinetics and acid-base accounts. In situations where the overlying strata are alkaline, infiltrating waters become alkaline and may be sufficiently alkaline to neutralize the acid formed by pyritic oxidation. (This results in a neutral pH discharge characteristically high in sulfate.) As long as the environment surrounding the pyrite is kept at a neutral pH, pyrite oxidation is very slow. Only at low pH's do the iron-oxidizing bacteria flourish and the oxidation rate skyrockets.

If sufficient alkalinity can therefore be imparted to the infiltrating water, the potential exists to control the acid-producing reaction. This concept was tested full-scale in the coal fields in eastern Ohio by EPA.[13, 14, 15] In the eastern Ohio situation, a highly porous spoil with acidic seeps was covered by varying quantities of low-grade limestone. The intent was to load the infiltrating water (rainfall and snowmelt) with alkalinity, thus slowing the acid production reaction as the water infiltrated the porous spoil.

These studies were marginally successful. Although reductions in acid load were observed at most sites, only the mildly acidic seeps were converted from acid to alkaline. For the worst situations, it was not possible to dissolve sufficient calcium carbonate to provide enough alkalinity to maintain a neutral internal environment.

This observation gave rise to the concept of using a more soluble neutralization reagent (e.g., sodium carbonate or sodium hydroxide) to provide a higher alkalinity input. Caruccio, Geidel, and Williams[16] took this a step further and integrated other observations to develop a new and radical approach. In studies conducted in West Virginia, they observed that the typical hydrogeology at surface-mined sites did not develop the classic wetting front. Instead, a "pseudo-Karst" hydrologic setting, characterized by highly permeable channels that are randomly located and interconnected within the backfill, was observed. If the "pseudo-Karst" concept holds true, most of the acid transport would occur in main drainage channels within the backfill rather than in a more uniformly distributed system. Caruccio and Geidel used these observations to try an "alkaline trench." They encouraged water infiltration into the backfill (a radical departure from existing technology) through a series of alkaline trenches. These trenches were filled first with a few inches of sodium bicarbonate (soda ash) briquettes and then covered with 2-3 feet of limestone reject. The concept of this approach is that the sodium bicarbonate, which is very soluble, will supply slug of high alkalinity over a 1-year period or so, which should convert most of the major acidity producers within the spoil from acid to alkaline conditions and slow the pyritic oxidation. The limestone should last for years, providing a low alkalinity residual to maintain alkaline conditions within the major flow channels within the spoil.

The first tests of this concept are now about 2 years old and show very promising results. One of the four seeps has changed from acidic to alkaline; all showed dramatic reductions in acidity. Acidity levels have dropped from pre-conditions averaging 600 to 800 mg/l to about 25 mg/l. Sulfate levels have dropped from 1,400 mg/l to 200 mg/l. The reduced sulfate levels signify dramatic reductions in the rate of pyrite oxidation. The acidity is now down to levels where surface application of limestone, as studied by Kalb and Geidel, should be effective. The dissolution of limestone by rainwater will produce about a 60 mg/l alkalinity. Caruccio has applied 100 tons/acre of limestone to the area now, spread uniformly over the entire surface, with the expectation of completely changing the ecosystem from acid to alkaline.

Microbial Control

It is unquestioned that pyrite oxidizing bacteria grossly enhance the oxidation rate in the natural setting. These bacteria (Thiobacillus ferrooxidans) are ubiquitous. If it were possible to control the bacteria, it would be possible to control the rate of the AMD formation reaction. Bacteriacides can be successfully applied in the laboratory; however, field tests are infinitely more complex. The most significant strides using this approach have been by Kleinman and Erickson[17] of the U.S. Bureau of Mines, who applied anionic surfactants (wetting agents/detergents) to two coal mining refuse piles in West Virginia with excellent success. Kleinman and Erickson applied 55 gal/acre of 30 percent sodium lauryl sulfate using hydroseeders and road watering trucks and achieved between 60-95 percent acidity production reduction after 5 months. Kleinman reports[18] that acid production can be generally reduced between 60 and 90 percent and that more than 30 mining companies are now spraying refuse piles approximately three times per year at about $300/acre.

Last Resort

Contingency planning is essential. Should all the best laid plans go astray, it is essential to plan for potential excursions from alkaline conditions. Therefore, it is important to control drainage as much as possible from the site into a single channel. Provision should be made for easy diversion of the flow into a settling facility, the overflow from which would return to natural drainage. Should the need for treatment develop, several processes are available for field situations (no electrical power, remote locations). Perhaps the simplest technique is soda ash briquette neutralization, which involves simply placing baskets of briquettes in the flowing stream for pH adjustment. More versatile and sophisticated treatment is available using liquid caustic (sodium hydroxide) which is metered into the stream by a special flume. The sodium hydroxide flows by gravity from a storage tank located conveniently nearby. Although these are rare, very mildly acidic, low iron seeps may be successfully treated with limestone aggregate beds placed in the stream channel.

For extreme cases involving high acidity and larger flows, economics may dictate consideration of full-scale lime or limestone neutralization facility construction.

In all cases of neutralization, provision must be made for settling. It is not sufficient to neutralize the acidity, form the hydroxide flocs, and allow these to discharge to the stream. A sedimentation/settling pond must be incorporated into the treatment scheme to prevent the discharge of the sludge into the receiving stream.

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